Wilson Bull., 109(1), 1997, pp. 131–144

HOME RANGE AND HABITAT USE OF RED-SHOULDERED HAWKS IN GEORGIA

DOUG L. HOWELL[1,2] AND BRIAN R. CHAPMAN[1]

ABSTRACT.—Home range and habitat use of Red-shouldered Hawks (*Buteo lineatus*) were studied within a managed pine forest in the Georgia Piedmont during the breeding season of 1994. The average home-range size was 127.9 ± 2.4 (SD) ha for four males and 97.0 ± 12.1 (SD) ha for three females. Home-range size of three breeding pairs averaged 133.0 ± 4.5 (SD) ha. Red-shouldered Hawks were located almost exclusively within forested habitats (96% of locations). The overall pattern of habitat use for both sexes was similar. Bottomland hardwoods were used more often than expected, and upland hardwoods were used in proportion to availability at two spatial scales. Pine and non-forested habitats were used less often than expected relative to availability. Male and female core areas averaged 37% of the mean home-range size. *Received 2 Nov. 1995, accepted 20 Sept. 1996.*

Although the Red-shouldered Hawk (*Buteo lineatus*) is a widespread, permanent resident over much of the Southeast, including Georgia, no quantified information exists on its space and habitat requirements within the region. Therefore, it is difficult to predict or mitigate possible impacts of habitat alterations associated with modern, intensive production of pine timber. The objectives of this study were to establish the home range size and habitat requirements of the Red-shouldered Hawk within an intensively-managed pine forest. Silvicultural treatments associated with intensive timber management result in a wide array of forest modifications that may alter horizontal and vertical structural diversity, decrease stand diversity, or alter the size class distribution and species composition of vegetation (Nelson and Titus 1988). Such habitat alterations may affect the viability of raptor populations by influencing the availability of nest sites, habitat use, and prey abundance and vulnerability. Therefore, studies such as this may provide information useful in formulating a management plan for Red-shouldered Hawks in managed forests of the Southeast.

METHODS

Study area.—We studied Red-shouldered Hawks during the 1994 breeding season on the Bishop F. Grant Memorial Forest (BGF), in Putnam and Morgan counties, approximately 14 km north of Eatonton (33°25′W, 83°28′N), in east-central Georgia. The 5718-ha study area lies within the southern Piedmont, a region of broad, gently sloping topography with occasional steep or strongly sloping terrain around the major drainage basins (Wharton 1977). Elevation ranges from 120–220 m above sea level. Rainfall averages approximately 120 cm per year (USDA-SCS 1965, 1976), with peak precipitation occurring in winter.

[1] Daniel B. Warnell School of Forest Resources, Univ. of Georgia, Athens, Georgia 30602-2152.
[2] Present Address: Directorate of Public Works and the Environment, AFZA-PW-DW, Wildlife Branch, Ft. Bragg, North Carolina, 28307-5000.

Eighty-five percent of BGF is forested, and is managed principally for the production of pine timber by the Daniel B. Warnell School of Forest Resources at the Univ. of Georgia. Fifty-five percent of the BGF land area consists of stands of loblolly pine (*Pinus taeda*). Pine habitats are managed with both natural and artificial regeneration methods combined with thinning and prescribed burning. Pine habitats are categorized by age-class and structural characteristics, and include <6 yr (clearcut), 6–20 yr (regeneration), 21–30 yr (pulpwood), 31–50 yr (sawtimber), and >50 yr (old sawtimber) stands.

Clearcuts typically consist of pine seedlings interspersed with several species of perennial grasses, including broomsedge (*Andropogon virginicus*) and plumegrass (*Erianthus* spp.), scattered hardwood sprouts, and blackberry (*Rubus* spp.) thickets. Regenerating stands are dominated by pines, with understory vegetation suppressed by shade and pine needles. The remaining age-classes have been thinned to various degrees, and represent product classes from pulpwood to sawtimber. Understory species include sweetgum (*Liquidambar styraciflua*), flowering dogwood (*Cornus florida*), and black cherry (*Prunus serotina*). Ground cover includes broomsedge, blackberry, and muscadine (*Vitis rotundifolia*). Prescribed winter burns every 3–5 years reduce fuel loads and competition from hardwoods.

Bottomland hardwood forests (7% of area) exist along the area's major drainages; Big Indian Creek, Glady Creek, and Little River. Dominant canopy species include green ash (*Fraxinus pennsylvanicus*), sweetgum, boxelder (*Acer negundo*), river birch (*Betula nigra*), sycamore (*Platanus occidentalis*), overcup oak (*Quercus lyrata*), water oak (*Q. nigra*), and willow oak (*Q. phellos*). The understory includes red maple (*Acer rubrum*), ironwood (*Carpinus caroliniana*), and American elm (*Ulmus americana*). Possum haw (*Ilex decidua*), switch cane (*Arundinaria gigantea*), and privet (*Ligustrum sinense*) dominate the shrub layer, while microstegium (*Microstegium vimineum*) and Christmas fern (*Polystichum acrostichoides*) are the dominant ground cover.

Upland hardwood stands (23%) lie adjacent to the bottomland corridor, or are associated with the major drainage basins. Dominant canopy species include white oak (*Quercus alba*), southern red oak (*Q. falcata*), pignut hickory (*Carya glabra*), blackgum (*Nyssa sylvatica*), sweetgum, and winged elm (*Ulmus alata*). The mid-story is dominated by flowering dogwood, and the shrub layer is dominated by sparkleberry (*Vaccinium arboreum*), deerberry (*V. stamineum*), and highbush blueberry (*V. corymbosum*). Common ground cover species include muscadine and poison ivy (*Toxicodendron radicans*). The remainder of BGF is maintained as pasture (14%) for cattle grazing and hay production by the College of Agriculture at the Univ. of Georgia, or is planted as wildlife openings (1%). In addition, several small reservoirs provide irrigation water, public fishing, and waterfowl habitat.

Capture and radio-telemetry.—We captured Red-shouldered Hawks with a modified dho-ghaza (Hamerstrom 1963) with a live Red-tailed Hawk (*B. jamaicensis*) as the lure. One female hawk which did not respond to the dho-ghaza was captured with a bal-chatri trap (Berger and Mueller 1959) baited with a black rat (*Rattus rattus*). Sex and age of each hawk were determined based on the presence or absence of a brood patch, body mass, and plumage characters (Clark and Wheeler 1987).

All hawks were fitted with radio-transmitters (Telonics Inc., Mesa AZ) and banded with a U.S. Fish and Wildlife Service aluminum leg band. Transmitters had a range of 2 km, and were attached in a backpack configuration (L. Schueck, Greenfalk Consultants, pers. commun.) with tubular teflon ribbon. Each transmitter included an activity sensing "tip-switch" that resulted in the transmission of two different pulse rates, depending on the orientation of the transmitter to the ground (i.e., perched or flying). The combined mass of the transmitter and harness (18–26 g) was <5% of each hawk's body mass. Soon after release, all radio-tagged hawks resumed normal activities, and no problems associated with the radio attachment method were observed.

We determined the locations of radio-tagged hawks by triangulation with a hand-held, four-element yagi antenna and visual sightings. At least three compass bearings were taken sequentially within 15 min to determine each hawk's location. All bearings were taken from predetermined locations (stations) along the existing road system, which allowed us to minimize the distance between the receiver and a transmitter, reduce signal bounce due to topography, and maintain angles for triangulation near 90°. Bearing standard deviation was estimated by conducting field trials with transmitters in 10 known locations (White and Garrott 1990). Two-hundred test bearings were used to calculate a mean bearing error of ± 3.02°. Universal Transverse Mercator (UTM) coordinates of receiver stations and locations of test transmitters were established with a mobile global positioning system (GPS Pathfinder Basic Plus, Trimble Navigation, Sunnyvale, California), and differentially corrected to an accuracy of ± 2 m.

We located radio-tagged hawks during five periods covering their movements from morning (1 h before sunrise) to night (1 h after sunset) roosts: 06:00-08:59 h; 09:00–11:59 h; 12:00–14:59 h; 15:00–17:59 h; 18:00–21:00 h (EST). Observation periods were randomly allocated to ensure all periods were sampled with equal probability over the course of the breeding season. For this study, the breeding season was defined as that period from courtship and nest building (1 March) until the young had fledged, or had fledged but were still dependent on one or both adults (31 August). Frequently, after a hawk was located with telemetry, it was followed visually for several hours. Information on exact movement patterns and behaviors was recorded. Caution was exercised so visual monitoring of hawks had little effect on their normal activities.

Based on their frequent movements, locations of radio-tagged hawks were normally recorded at 30-min intervals. Movements were inferred from a noticeable change in transmitter signal strength and/or a change in the pulse frequency, followed by a change in signal direction. Locations were included only if the hawk was stationary as bearings were recorded. When hawks were monitored visually, each perch change >100 m was recorded as a location. Location estimates and 95% confidence ellipses for each triangulated location were calculated with maximum likelihood estimation (MLE) (Lenth 1981). The mean confidence ellipse size was 1.37 ± 0.46 (SD) ha (range = 0.1–3.5 ha). Most (79%) confidence ellipses were <1 ha. Hawk locations obtained visually (34% of locations) were recorded in the field on 7.5-minute U.S. Geological Survey topographic maps based on map landmarks and a global positioning system.

Home-range analysis.—We estimated the size and shape of Red-shouldered Hawk home ranges by the harmonic mean (HM) method (Dixon and Chapman 1980) with the computer program HOME RANGE (Ackerman et al. 1990). The contour line encompassing 95% of all locations for an individual hawk was used as the home-range boundary. Core areas were identified by comparing the observed space-use pattern (utilization distribution) of hawks with that expected from a uniform pattern of use (Samuel and Green 1988). Core areas included the maximum area where the observed utilization distribution (based on harmonic values) exceeded a uniform utilization distribution. All harmonic mean calculations were based on a grid size of 75 m. The minimum convex polygon (MCP) home range (Mohr 1947) was estimated to permit comparisons with earlier studies.

The index of autocorrelation (gamma) recommended by Swihart and Slade (1986) was used to assess the level of autocorrelation in the locational data. We assumed gamma values >0.3 indicated significant autocorrelation (Ackerman et al. 1990). We calculated the "time to independence" (Swihart and Slade 1986) for each hawk with the HOME RANGE program. For all hawks, the level of autocorrelation was reduced to an insignificant level (gamma <0.3) at a 2-h sampling interval. Therefore, only observations separated by two hours or more were used in analyses of home range and habitat use in order to meet assumptions of independence.

Habitat-use analysis.—We developed a digital database with the geographic information system (GIS) software package ARC/INFO (ESRI 1991) to estimate the area of each habitat type within the study area, and within each hawk home range. The boundaries of habitat polygons were delineated from aerial photographs and forest cover maps, then transferred to the GIS using a digitizer. Aerial photographs, forest cover maps, and forest stand information were obtained from the Univ. of Georgia. The contour line defining the 95% HM home range and core area for each hawk was transferred from HOME RANGE to the GIS as a UTM coordinate file. Estimated locations were entered directly into the database as UTM coordinates to determine habitat characteristics at each location.

Using the GIS, we assessed potential habitat misclassification in the telemetry data (N = 1242 location points) resulting from bearing error (Howell 1995). We assumed a circle with a uniformly distributed radius corresponding to the size of the 95% MLE confidence ellipse was representative of telemetry error for each location. Confidence ellipses were overlayed with the computerized habitat availability map to determine the number of habitat types occurring within an ellipse. We assumed a confidence ellipse containing > 1 habitat type represented potential habitat misclassification.

We used Chi-square analysis (Neu et al. 1974) to test the hypothesis that hawks used habitat types in proportion to availability. When this hypothesis was rejected, Bonferroni confidence intervals (Byers et al. 1984) were used to determine which habitat types were used more or less often than expected. Because a species response to habitat variation (selection) may occur at more than one level (Johnson 1980), the number of locations within each habitat type was compared with habitat availability at two spatial scales: (1) within each individual hawk home range, and (2) among all hawks within the study area (landscape level). At the landscape level, available habitat was estimated from the combined 95% HM contour for all hawks. A Chi-square test was also performed to compare the proportional distribution of habitats within hawk home ranges to that expected by relative availability within a broader landscape, represented by the study area boundary. To assure a reasonable approximation to the Chi-square distribution, the 20–30 yr (pulpwood) and 31–50 yr (sawtimber) stands were pooled into a 21–50 yr pulpwood/sawtimber stand class (Neu et al. 1974). The significance level was set at 0.05 in all tests.

RESULTS

Radio-telemetry.—We radio-tracked five male and two female Red-shouldered Hawks between 14 April and 22 August 1994. Monitoring periods ranged from 59 to 102 days (average 88), totaling 656 hours of continuous observation. Removal of location points to reduce autocorrelation resulted in 1870 useable location points (Table 1). Except for one male, all hawks were territorial breeding adults. Both members of two breeding pairs (F170-M090, F190-M010) were tracked simultaneously for ≥95 days (see Table 1 for hawk codes). An adult female (F210) was observed, but not radio-tagged, for 76 days; she nested successfully with M030. There were sufficient locations to estimate the size and shape of her home range, but F210 was excluded from analysis of habitat use.

Male home-range size.—The 95% HM home range of four male Red-shouldered Hawks averaged 127.9 ± 2.4 (SD) ha (range = 126.1–131.5

TABLE 1
HOME-RANGE SIZE (HA) OF EIGHT RESIDENT RED-SHOULDERED HAWKS IN THE GEORGIA PIEDMONT, APRIL–AUGUST 1994

Hawk[a]	No. locations	Days monitored	Harmonic mean		Convex polygon	
			Core area (%)[b]	95%	95%[c]	100%
M010	316	96	50.5 (60)	131.5	154.9	301.3
M030	312	94	48.6 (62)	126.1	151.7	198.5
M050	337	82	51.6 (60)	127.3	131.5	168.3
M070[d]	168	59	—	3069.6	3133.9	3297.2
M090	312	94	58.0 (61)	126.7	143.9	163.0
F170	285	102	50.0 (65)	108.8	108.9	160.3
F190	308	95	40.4 (62)	97.6	87.5	135.5
F210	127	79	32.6 (61)	84.6	91.3	114.8

[a] M = male, F = female. Includes 3 breeding pairs (F170-M090, F190-M010, M030-F210).
[b] (%) = percent of utilization volume.
[c] Excludes outer 5% of location estimates.
[d] Subadult hawk that was a non-territorial "floater."

ha; Table 1). One subadult male (M070) was excluded from analysis because he failed to maintain a home range in the traditional sense. Although his movements seemed to center around a small riparian corridor, M070 was tracked within the home range of three other pairs, and his movements were erratic. His 95% HM home range was 24 times larger than the mean home-range size of other males (Table 1). Male home ranges were on average, 24% larger than females (range = 13.7–35.7%), and when considering only breeding pairs, generally encompassed those of their mates (Fig 1).

Although males ranged widely, all their home ranges included areas that received concentrated use. These core areas averaged 52.2 ± 4.0 (SD) ha (range = 48.6–58.0 ha; Table 1), representing only 37% (range = 34.4–43.6%) of the average male home range. All male core areas contained the nest site, but were most often centered around a small beaver (*Castor canadensis*) pond, wet meadow, or an area containing many small seasonally or permanently flooded pools. On average, approximately 61% (range = 59.6–62.0%) of male locations fell within the core area, based on harmonic mean estimates (Table 1).

Female home-range size.—The 95% HM home range of three female Red-shouldered Hawks averaged 97.0 ± 12.1 (SD) ha (range = 84.6–108.8 ha; Table 1). Female home-range size varied over the course of the breeding season. Home-range size was smallest during incubation, averaging only 30 ± 7.8 (SD) ha, but increased through brood-rearing as females foraged over wider areas. For example, during the incubation

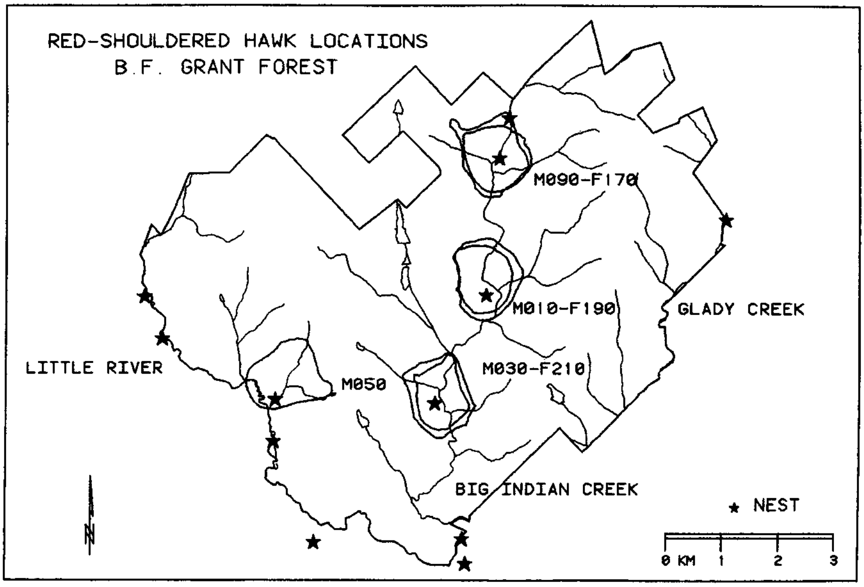

FIG. 1. Map of the Red-shouldered Hawks known to occupy the area within and adjacent to the Bishop F. Grant Memorial Forest; includes the home ranges of three breeding pairs (M090-F170; M010-F190; M030-F210) and an adult male (M050) followed April–August, 1994.

period, F170 rarely moved from the vicinity of her nest, but began making regular visits to a small beaver pond shortly after the first chick appeared.

Female core areas averaged 41.0 ± 8.7 (SD) ha (range = 32.6–50.0 ha; Table 1), representing only 37% (range = 35.2–40.5%) of the average female home range. Female core areas were centered on the nest and included intensively-used foraging sites. On average, 63% (range = 61.8–65.2%) of female locations fell within the core area (Table 1). Female core areas averaged 21% (range = 0–43.7%) smaller than those of males.

Pair home-range size.—The three breeding pairs of Red-shouldered Hawks (see Table 1) occupied adjacent home ranges along the Big Indian Creek corridor, which bisected BGF (Fig. 1). The combined 95% HM home range of breeding pairs averaged 133.0 ± 4.5 (SD) ha (range = 132.1–134.3 ha). Approximately 75% of a pair's home range was used by both members, while the remaining 25% was used only by the male. Areas of overlap generally encompassed both the male and female core areas. There was no overlap between home ranges of either member of adjacent pairs, and no intraspecific territorial encounters were observed.

Habitat composition within home ranges.—Forested habitats comprised more than 91% of Red-shouldered Hawk home ranges (excluding M070, F210; Table 2). Of the forested habitats, bottomland (32.1%) and upland (21.4%) hardwoods were the most common. Stands of old sawtimber, regeneration, and pulpwood/sawtimber represented 19.6%, 16.3%, and 2.2% of home ranges, respectively. The non-forested habitats, pasture (4.5%) and clearcut (3.9%), were relatively rare in hawk home ranges. Approximately 77% and 78% of male and female core areas, respectively, consisted of bottomland and upland hardwoods.

Habitat-use patterns within home ranges.—Chi-square tests of habitat selection within home ranges were significant ($P < 0.001$) for all hawks ($N = 6$) available for analysis (Table 3). All hawks used bottomland hardwoods more often than expected, while use of upland hardwoods was proportionate to area (Bonferonni Z-test, $P < 0.05$). In general, non-forested habitats, regeneration, and pulpwood/sawtimber were not present within home ranges, not used, or used less often than expected relative to availability; old sawtimber was used in proportion to availability, or less often than expected.

Habitat-use patterns within study area.—Habitat use within the study area was not random. For both males and females, the observed number of radio locations differed from expected, based on the area of each habitat type within home ranges (males–$\chi^2 = 481$, df = 6, $P < 0.001$; females–$\chi^2 = 146.8$, df = 6, $P < 0.001$) (Table 3). The overall pattern of habitat use for both sexes was similar (Bonferonni Z-test, $P < 0.05$). Both males and females used bottomland hardwoods more often than expected, based on its availability, while use of upland hardwoods was approximately proportionate to area. Most (78%) locations were in bottomland (56.9%; males, 693 of 1277; females, 371 of 593) and upland hardwoods (21.0%; males, 300 of 1277; females, 93 of 593), respectively (Table 2). Regeneration, pulpwood/sawtimber, and old sawtimber stands were used less often than expected, representing 17.8% of the observed habitat use (males, 178 of 1277; females, 74 of 593 locations). Red-shouldered Hawks used non-forested habitats less often than expected based on availability. Collectively, pasture and clearcut represented only 4.3% of observed habitat use (males, 72 of 1277; females, 46 of 593 locations), but make up (18%) of the area.

The distribution of habitat types within hawk home ranges ($N = 6$) differed from expected based on their relative availability within BGF ($\chi^2 = 98$, df = 6, $P < 0.001$). Overall, home ranges contained more bottomland forests, while the proportion of upland hardwoods was equal to availability (Bonferonni Z-test, $P < 0.05$). In addition, home ranges contained less pasture, clearcut, and old sawtimber, while the proportions of regen-

TABLE 2

PERCENTAGE OF DIFFERENT HABITATS WITHIN THE 95% HARMONIC MEAN HOME RANGE AND PERCENTAGE OF ESTIMATED LOCATIONS WITHIN DIFFERENT HABITATS

Habitat[a]	Hawk number													
	M010		M030		M050		M090		F170		F190		All hawks	
	Hab.	Loc.	Hab.	Loc.	Hab.	Loc.	Hab.	Loc.	Hab.	Loc.	Hab.	Loc.	Hab.	Loc.
BLHW	42.8	66.8	19.6	46.6	23.0	55.8	30.6	47.7	29.2	49.2	50.8	75.0	32.1	56.9
UPHW	18.1	15.8	29.6	28.0	20.2	23.7	23.6	26.6	21.4	21.5	14.2	10.4	21.4	21.0
PAST	6.2	4.1	10.6	5.5	1.9	+	1.2	+	1.4	+	5.3	2.6	4.5	2.3
C-CUT			7.3	7.4			8.4	2.9	7.6	2.1			3.9	2.0
REGEN	18.5	5.4	23.6	2.9	14.7	+	10.7	3.5	11.6	7.4	18.6	6.2	16.3	4.3
21–50 YR	1.1	+					6.7	3.2	4.0	1.8	1.2	+	2.2	1.1
>50 YR	13.3	7.3	9.3	9.6	40.2	19.0	18.8	15.4	24.8	17.9	9.9	5.2	19.6	12.4

[a] Habitat codes: BLHW = bottomland hardwood; UPHW = upland hardwood; PAST = pasture; C-CUT = clearcut; REGEN = regeneration; 21–50 YR = pulpwood/sawtimber; >50 YR = old sawtimber; + = <1%; N = 1870 locations.

TABLE 3
HABITAT SELECTION BY SIX RED-SHOULDERED HAWKS IN THE GEORGIA PIEDMONT, APRIL–AUGUST 1994[a]

	Hawk[b]						All hawks[c]	
Habitat	M010	M030	M050	M090	F170	F190	M	F
BLHW	+1	+1	+1	+1	+1	+1	+1	+1
UPHW	0	0	0	0	0	0	0	0
PAST	0	−1	NU	NU	−1	−1	−1	−1
C-CUT	NP	0	NP	−1	−1	NP	−1	−1
REGEN	−1	−1	NU	−1	−1	−1	−1	−1
21–50 YR	NU	NP	NP	−1	−1	NU	−1	−1
>50 YR	−1	0	−1	0	−1	−1	−1	−1

[a] Selection evaluated using chi-square tests with Bonferonni confidence intervals (Neu et al. 1974); 0 = use of habitat equal to expected; −1 = use of habitat less than expected; +1 = use of habitat greater than expected; NU = not used; NP = not present within home range.
[b] Available habitat sampled from individual 95% HM home range.
[c] Available habitat sampled from combined 95% HM contour.

eration and pulpwood/sawtimber were equal to their relative availability within the study area.

Habitat misclassification.—Potential habitat misclassification due to bearing error had little effect on the habitat-use analyses. Eighty-seven percent of the MLE confidence ellipses (N = 1242) contained only one habitat type (Howell 1995). Sixty-six percent of potential misclassification (107 of 162 locations) represented a confidence ellipse containing bottomland (28%) or upland hardwoods (38%). Most (45%) of the potential misclassification represented a bottomland hardwood/upland hardwood or upland hardwood/bottomland hardwood misclassification matrix and reflected the heavy use of the bottomland—upland ecotone.

DISCUSSION

Home range.—Home-range estimates for Red-shouldered Hawks on BGF support previous findings that suggest the species uses the smallest home range of any North American buteonine raptor studied to date. Parker (1986) reported a mean MCP of 118 ± 13 ha for two males in Missouri, an estimate similar to this study (mean MCP = 145 ± 10 ha, N = 4 males). In an intensive study of the western subspecies (*B. l. elegans*), Bloom et al. (1993) found the mean home range (95% HM) of seven males was 121 ± 35 ha, and six females was 101 ± 19 ha, similar to the home-range size of males (128 ± 2 ha) and females (97 ± 12 ha) reported here.

The location and shape of home ranges were influenced by the topographic characteristics of the bottomland habitats within the study area.

Almost all home ranges were found within the widest portions of the bottomland corridor, normally in areas fed by one or more perennial streams. These areas held seasonal floodwaters and precipitation as temporary or permanent pools, contained beaver ponds, and likely provided a diverse and abundant source of prey. Sixty percent of the prey delivered to eight Red-shouldered Hawk nests on BGF (Howell 1995) were those associated with or found only in aquatic or moist habitats. Red-shouldered Hawk core areas generally conformed to the distribution of the temporary or permanent pools and small open wetlands ($\leq$1 ha) within the home range.

Home ranges of Red-shouldered Hawks on BGF were rather evenly distributed along the bottomland corridor of the areas three main waterways (Fig 1). The nests of 12 pairs that occupied BGF were generally separated by approximately 2 km. Stewart (1949) and Henny et al. (1973) noted that Red-shouldered Hawks occupied evenly distributed home ranges along floodplain forest corridors in Maryland. Newton (1979) suggested that in continuously suitable habitat, nesting pairs of raptors are often separated by roughly equal distances, thus reducing interference in breeding and hunting.

The three breeding pairs of Red-shouldered Hawks that we tracked occupied mutually exclusive home ranges (Fig. 1). Bloom et al. (1993) reported an overlap of only 5% between adjacent home ranges of three breeding pairs in California. In both instances where adjacent nests were located $<$1 km apart, one of the two pairs either abandoned the nest or failed to produce young (D. L. Howell and C. E. Moorman, pers. obs.). Henny et al. (1973) found that as the distance between adjacent Red-shouldered Hawk nests decreased, nesting success decreased, and concluded nest success was inversely proportional to the number of breeding pairs present.

Habitat use.—Red-shouldered Hawks on BGF hunted almost exclusively within forested habitats, employing still-hunting from perches as the primary foraging method. Bednarz and Dinsmore (1981), Parker (1986), and Bloom et al. (1993) showed similar trends of preference for forested habitats by Red-shouldered Hawks. Bloom et al. (1993) suggested that Red-shouldered Hawks in California were limited in their use of non-forested habitats by the availability of perches. On BGF, both pastures and clearcuts contained ample perches from which hunting attempts could be initiated. However, these open habitats were also favored habitats of resident Red-tailed Hawks (Moorman and Chapman 1996), which may have deterred use by Red-shouldered Hawks. Red-tailed and Red-shouldered hawks usually maintain mutually exclusive feeding territories in North America (Bent 1937, Craighead and Craighead 1956).

Among the forested habitats, pine stands represented only about 18% of the observed habitat use. The limited use of regeneration areas was not surprising. These were densely stocked (approximately 3600 stems/ha) stands with closed canopies, which generally hold little prey value for raptors until thinning resumes (Langley and Shure 1980). Here, Red-shouldered Hawks normally concentrated their foraging efforts along old fire-breaks, which had regrown to perennial grasses and could be hunted from perched positions along an adjacent woodland edge, normally a bottomland or upland hardwood corridor.

The overall use of pine habitats was linked to the age and structure of the stands. Red-shouldered Hawks rarely used young pulpwood stands that had received only one thinning (Tables 2 and 3). Use was greatest within old sawtimber stands that had received at least two thinnings, or were present as shelterwood regeneration and where regular prescribed burning had created a open understory (Table 2). This may be a reflection of prey abundance, and the ability of a hawk to detect and capture prey in more open forests.. King (1982) found that both numbers and biomass of small mammals were greater in mature loblolly pine stands (i.e., a mean age of 57 yr) with a regular burning regime (1–4 yr) than in only thinned or unmanaged stands. Pulpwood stands were densely stocked (1200 stems/ha), and may have limited a hawk's maneuverability relative to older, more open stands. In addition, the hardwood understory in these stands had not been removed by winter burns, which may have limited hawks' ability to detect and capture prey. Studies of Swainson's Hawks (*B. swainsoni*) and Ferruginous Hawks *(B. regalis)* found vegetative cover limited access to prey, and influenced hawk selection of foraging sites (Wakeley 1978, Bechard 1982).

Although Red-shouldered Hawks foraged widely, they tended to remain within bottomland hardwoods, concentrating their hunting efforts within relatively small portions of their home range. The use of upland hardwoods was restricted to areas immediately adjacent to the bottomland corridor, or along the drainage of small perennial streams that flowed into a major water-course. Hawks would often position themselves to hunt the ecotone between the two habitats. Similar habitat use by Red-shouldered Hawks was noted in Iowa (Bednarz and Dinsmore 1981) and California (Bloom et al. 1993).

The Red-shouldered Hawk's association with forested wetland habitats is well-documented (Bednarz and Dinsmore 1981, 1982), but characteristics of its home range and habitat use within an intensively-managed forest in the Southeast were previously undescribed. The pattern of habitat selection for bottomland hardwoods relative to other habitats was identical when available habitats were sampled from the study area (second-order selection, Johnson 1980), or from within individual home ranges (third-order selection), suggesting this habitat may be a limiting factor on BGF. We suggest that 133 ha of mature bottomland forest, interspersed with seasonally or permanently flooded pools and small open wetlands (≤ 1 ha) provides adequate space and habitat for one pair of Red-shouldered Hawks if adequate prey densities are also available.

Areas of upland hardwoods adjacent to the bottomland corridor should be maintained in a managed forest as buffer habitats. These areas can provide food when prey availability is low within the bottomland forest, and can limit competition from Red-tailed Hawks. Bednarz and Dinsmore (1981) found that upland forests may compensate for limited floodplain forest around some Red-shouldered Hawk nests in Iowa, and may discourage competition from Red-tailed Hawks, a species adapted to more open habitats. Forest clearing and development of pastures along drainage systems shifts the competitive advantage from Red-shouldered to Red-tailed Hawks in bottomland forests (Bednarz and Dinsmore 1982). Where intensive management for pine timber results in the reduction of bottomland forests to narrow corridors or streamside management zones surrounded by young pine plantations, the habitat available to Red-shouldered Hawks becomes less suitable, and thus may accelerate incursion by Red-tailed hawks.

ACKNOWLEDGMENTS

We thank the staff of Bishop F. Grant Memorial Forest, particularly A. Harris, for housing and on-site logistical support. C. E. Moorman provided invaluable field assistance and support throughout the project. Special thanks to C. Howell, J. Gallagher, K. James, M. Kelly, and J. Gantt for their assistance with trapping and radiotelemetry. D. G. Krementz and A. S. Johnson reviewed earlier drafts of the manuscript. This manuscript was improved by comments provided by J. C. Bednarz, J. J. Dinsmore, C. R. Blem, and an anonymous referee. Funding was provided by the Daniel B. Warnell School of Forest Resources at the Univ. of Georgia and McIntire Stennis Project No. GEO-0074-MS.

LITERATURE CITED

ACKERMAN, B. B., F. A. LEBAN, M. D. SAMUEL, AND E. O. GARTON. 1990. User's manual for program HOME RANGE. 2nd edition. Tech. Rep. 15, For., Wildl. and Range Exp. Stn., Univ. Idaho, Moscow, Idaho.

BECHARD, M. J. 1982. Effect of vegetative cover on foraging site selection by Swainson's Hawk. Condor 84:153–159.

BEDNARZ, J. C. AND J. J. DINSMORE. 1981. Status, habitat use, and management of Red-shouldered Hawks in Iowa. J. Wildl. Manage. 45:236–241.

——— AND ———. 1982. Nest-sites and habitat of Red-shouldered and Red-tailed Hawks in Iowa. Wilson Bull. 94:31–45.

BENT, A. C. 1937. Life histories of North American birds of prey. Part 1. U.S. Natl. Mus. Bull. No. 167.

BERGER, D. D. AND H. C. MUELLER. 1959. The bal-chatri: a trap for the birds of prey. Bird-Banding 30:18–26.

BLOOM, P. H., M. D. MCCRARY, AND M. J. GIBSON. 1993. Red-shouldered Hawk home-range and habitat use in southern California. J. Wildl. Manage. 57:258–265.

BYERS, C. R., R. K. STEINHORST, AND P. K. KRAUSMAN. 1984. Clarification of a technique for analysis of utilization-availability data. J. Wildl. Manage. 48:1050–1053.

CLARK, W. S. AND B. K. WHEELER. 1987. The Peterson field guide series: A field guide to hawks of North America. Houghton Mifflin Co., Boston, Massachusetts.

CRAIGHEAD, J. J. AND F. C. CRAIGHEAD, JR. 1956. Hawks, owls, and wildlife. Stackpole Co., Harrisburg, Pennsylvania.

DIXON, K. R. AND J. A. CHAPMAN. 1980. Harmonic mean measure of animal activity areas. Ecology 61:1040–1044.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE (ESRI). 1991. ARC/INFO. Redlands, California.

HAMERSTROM, F. 1963. The use of Great Horned Owls in catching Marsh Hawks. Proc. XIII Int. Ornithol. Congr. 13:866–869.

HENNY, C. J., F. S. SCHMID, E. L. MARTIN, AND L. L. HOOD. 1973. Territorial behavior, pesticides, and the population ecology of Red-shouldered Hawks in central Maryland, 1943–1971. Ecology 54:545–554.

HOWELL, D. L. 1995. Home range characteristics, foraging ecology, and diet of Red-shouldered Hawks (*Buteo lineatus*) in a managed pine forest in the Georgia Piedmont. M.S. thesis, Univ. Georgia, Athens, Georgia.

JOHNSON, D. H. 1980. The comparison of usage and availability measurements for evaluation of resource preference. Ecology 61:65–71.

KING, K. J. 1982. Effects of prescribed burning and thinning in natural Piedmont loblolly-shortleaf pine stands on small mammal populations. M.S. thesis, Univ. Georgia, Athens, Georgia.

LANGLEY, A. K., JR. AND D. J. SHURE. 1980. The effects of loblolly pine plantations on small mammal populations. Am. Midl. Nat. 103:59–65.

LENTH, R. V. 1981. On finding the source of a signal. Technometrics 23:149–154.

MOHR, C. O. 1947. Table of equivalent populations of North American small mammals. Am. Midl. Nat. 37:223–249.

MOORMAN, C. E. AND B. R. CHAPMAN. 1996. Nest-site selection of Red-shouldered and Red-tailed Hawks in a managed forest. Wilson Bull. 108:357–368.

NELSON, B. B. AND K. TITUS. 1988. Silvicultural practices and raptor habitat associations in the Northeast. pp. 171–179 *in* Proc. Northeast Raptor Manage. Symp. and Workshop. Natl. Wildl. Fed., Washington, D.C.

NEU, C. W., C. R. BYERS, J. M. PEEK, AND V. BOY. 1974. A technique for analysis of utilization-availability data. J. Wildl. Manage. 38:541–545.

NEWTON, I. 1979. Population ecology of raptors. Buteo books, Vermillion, South Dakota.

PARKER, M. A. 1986. The foraging behavior and habitat use of breeding Red-shouldered Hawks (*Buteo lineatus*) in southeastern Missouri. M.A. thesis, Univ. Missouri, Columbia, Missouri.

SAMUEL, M. D. AND R. E. GREEN. 1988. A revised test procedure for identifying core areas within the home range. J. Anim. Ecol. 57:1067–1068.

STEWART, R. E. 1949. Ecology of a nesting Red-shouldered Hawk population. Wilson Bull. 61:26–35.

SWIHART, R. K. AND N. A. SLADE. 1986. The importance of statistical power when testing for independence in animal movements. Ecology 67:255–258.

USDA-SCS. 1965. Soil survey of Morgan County, Georgia. USDA Soil Conservation Service.

———. 1976. Soil survey of Baldwin, Jones, and Putnam Counties, Georgia. USDA Soil Conservation Service.

WAKELEY, J. S. 1978. Factors affecting the use of hunting sites by Ferruginous Hawks. Condor 80:316–326.

WHARTON, C. H. 1977. The natural environments of Georgia. Ga. Dep. Nat. Resour., Off. Planning Res., Resour. Planning Sec., Atlanta, Georgia.

WHITE, G. C. AND R. A. GARROTT. 1990. Analysis of wildlife radio-tracking data. Academic Press, Inc., San Diego, California.